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PULTRUDED PART AND METHOD OF PREPARING A REINFORCEMENT MAT FOR THE PART

Related Applications

This application claims priority under 35 U.S.C. 119 from provisional application Serial No. 60/155258 filed June 21, 1999. Provisional application Serial No. 60/155258 is fully incorporated herein by specific reference thereto.

Background of the Invention

1. Field of the Invention

This invention relates to a mat for use as reinforcement for the resin composition used in pultrusion of a pultruded part, and to a part which has been pultruded using the improved mat as a reinforcement for the resin composition. In particular, the invention concerns an improved reinforcement mat made up of a number of layers, including a layer having fibers which extend transversely of the mat, fibers that are oriented longitudinally of the mat, fibers that are arranged obliquely of the longitudinal and transverse fibers, entangling fibers that extend into the other fiber layers, and a binding resin for the fibers.

The invention is especially useful for pultrusion of parts for fenestration products and relates to a reinforcement mat for the pultrusion resin. Representative fenestration products in this respect include items such as pultruded window jambs, sills, heads, sash stiles or sash rails.

2. Description of the Prior Art

Pultrusion is a known technique in which longitudinally continuous fibrous elements, which can include roving and/or a mat, are combined into a structure. The process generally involves the pulling of the rovings and mats through a resin bath, and into a heated forming die. The heat of the die cures the resin, and the part is pulled through the die, on a continuous basis. The mat and roving are textile-type products, as they are flexible and conformable. Current pultruded parts are generally 1/4" or thinner, and in the fenestration industry, range from 0.07" - 0.1" thick. The pultruded parts are solid structures, and generally have a profile such as a box,

or open section, where the bends in the thin-profile give the pultrusion a high-degree of rigidity and structural integrity.

Mat and roving composite reinforcements are primarily glass products, while the resin matrix is usually, but not necessarily, a thermosetting polyester. Mat material is generally in the form of a non-woven mat, where glass fibers are randomly placed in a planar swirl pattern, resulting in a felt-like web.

Before pultrusion, glass rovings are groupings of up to thousands of microns-diameter glass fibers, that mechanically behave like flexible rope, because the diameter of each filament is so small, even though it is made of glass, commonly considered to be a rigid material. After pultrusion, the glass rovings are held together by the matrix resin, resulting in the rigidity of the pultrusion composite parts. In a pultrusion profile, the mat and roving constitute the reinforcement, while the resin constitutes the matrix of the solid composite.

The technique of pultrusion has been used for many years for manufacturing various parts including simple parts such as rods and more recently including parts of more complex and thinner cross-section. One requirement for thinner parts is that of providing fibers in the construction which are transverse to the length of the part to provide transverse strength.

The longitudinal strength of pultruded parts is very high since the majority of the fibers extend longitudinally in the form of a series of longitudinally extending rovings pulled through the die. However the transverse strength of pultruded parts is generally compromised because only a limited number of the fibers extend transversely.

Mats having transverse fibers and placed on opposite sides of the outside of a pultruded part have been tried in the past. Various types of mat materials are available but the mat material which is principally used is one in which the fibers are laid in random patterns in a flat layer and the fibers then held together by a binder which acts to attach crossing fibers at the junctions to form a two dimensional structure. This type of mat has high shear resistance due to the large number of interconnections between the randomly oriented fibers. However the main intention of the mat is to provide a high proportion of the fibers extending in the transverse direction and this is not achieved since the fibers extend in random directions. Therefore, only a very small proportion of the total fiber component extends in the transverse direction.

It has long been recognized that the absence of a suitable mat has significantly reduced the quality of pultrusions particularly in regard to the transverse strength, thus leading to limited penetration of pultruded parts into various marketplaces.

The conventional mat has also a number of serious problems which interfere with the efficiencies and economics of the pultrusion process.

First, the mat is a relatively expensive, and there is waste of offal when the mat is slit to width.

Second, the mat is difficult to form into the required complex shapes. Thick, strong mats are available but they are more difficult to bend and shape, before entering the die. Lightweight mats are easier to shape, but they lack transverse strength, and are more prone to ripping-out at the die entrance.

The choice of mat is therefore a compromise between the necessity for bending to shape and the required strength of the pultruded part.

More recently, mats have become available that are needled in a direction at right angles to the plane of the mat, to provide loops that cooperate with the rovings, and also form a mat structure which has greater bond strength in the through-thickness direction, to provide necessary pull strength. This mat has a tendency to stretch, and is very expensive, thus interfering with the economics of the pultrusion process.

Available reinforcing mats that are needled use continuous fibers rather than cut-staple fibers in order to provide the highest strength of the fibers. However, the needling tends to break at least some of the pulled glass fibers in order to effect their distortion from the plane of the mat, thus reducing the strength of the mat, because many of the fibers have been broken by needling.

United States Patent 4,058,581 (Park) discloses an attempt to attach discontinuous fibers to longitudinally continuous fibers by simply adding these into the bath of resin so that they may be picked up by the longitudinal fibers as they pass through the resin. There is no assertion by the supplier that this leads to a layer of transverse fibers in the part wall and it is believed that any fibers so attached would simply be pulled straight and longitudinal by passage through the die.

United States Patent 5,324,377 (Davies, one of the inventors herein) discloses a technique to add fibers transverse to the length of the part by extruding those fibers into the

outside of the part so that they are carried with the part through the die. Unfortunately this technique has not yet led to significant success so that the requirement for an improved mat has remained largely unfulfilled.

In order for the reinforcing mat to pass through the die with the longitudinal fibers, it is necessary for the mat to have a sufficient longitudinal strength that it does not tear as it is pulled through the die. Furthermore the mat must have a sufficient shear strength so that it does not twist or skew allowing one side edge of the mat to move in advance of the other side edge. If such twisting or skewing occurs, the mat will become distorted in the part and the mat eventually will break down if the distortion goes beyond a certain level thus bringing down the process and requiring a re-start.

The term "shear strength" used herein therefore relates to the resistance of the mat to twisting or skewing in the plane of the mat in a direction such that one edge of the mat moves in advance of the other edge of the mat.

Summary Of The Invention

The present invention overcomes the problems outlined above and provides an improved mat for use as reinforcement for a resin composition to be used in forming an elongated, pultruded part of constant transverse cross-section using a pultrusion die. The mat includes a first layer of continuous, generally longitudinally-extending fibers which provide longitudinal strength and increased modulus to the mat. A second layer of generally transverse reinforcement fibers is provided in association with the first layer of generally longitudinal fibers with the transverse fibers being oriented at an angle to provide transverse strength and increased modulus to the mat and thereby to the final pultruded part. A third layer of diagonal transport fibers for the transverse reinforcement fibers is provided with certain of the transport fibers preferably extending diagonally in one direction with respect to the first layer of generally longitudinally-extending fibers, and other fibers extending diagonally at an opposite, essentially equal angle to provide shear strength and increased modulus and anti-skewing resistance and stiffness to the mat when used for pultrusion of a part. A batting layer, preferably made up of B-staged thermoset or thermoplastic fibers, is provided with at least a portion of the batting fibers extending through the thickness of the mat layers to interconnect

the fibers of all of the layers to thereby increase the shape-retaining capability of the mat during pultrusion of the part.

The fibers of the longitudinally-extending first layer, the transverse layer and the transport layer are preferably glass fibers in the form of rovings of required individual cross-sectional area.

A quantity of a binding agent is also preferably provided which bonds all of the layers of the mat together. The binding agent is either added separately to the mat layers during preparation thereof, and may comprise a powder, solvent, thermal, or aqueous-based thermoplastic binder which adheres to the multiple layers of the mat and/or the interstices within a given layer.

Mat stiffness is the capability of the mat to retain its shape when subjected to tensile loading, and when subjected to shear loading, as a mat. Mat stiffness can be viewed as resistance to wrinkling and distortion when loaded by pulling, or by bending, which occurs when the mat is pulled over various shaped preformers, before the mat enters the die. With greater mat stiffness, mat skewing is reduced.

Mat strength and increased modulus as used herein is the ability of the mat to carry a load without distorting, tearing, stretching due to slippage or shearing between reinforcements, or stretching due to a compressive wrinkling or "buckling" of a reinforcement constituent of the mat. The mat strength and increased modulus is generally measured in pounds per lineal inch in a given direction.

The strength and increased modulus of the pultruded part refers primarily to the load-bearing capability of the pultruded part including transverse normal strength and transverse shear strength. The transverse strength of the pultruded part, generally indicated as "strength," or strength and increased modulus as used herein, allows for greater loading in the transverse direction, greater flex strength in the transverse direction, and resistance to tearing or cleaving in the longitudinal direction, for the pultruded part.

In the improved method of preparing a mat for use in reinforcing a pultrusion resin, the lay-up of mat layers including the fibrous batting layer are subjected to water-jets from hydro-entangling apparatus or from a series of barbed needles directed into the layered mat, both of which function to deflect the fibers of the batting layer to produce entangling fibers that extend through the thickness of the mat layers and interconnect the fibers of the layers, thus increasing

the shape-retaining capability of the mat. Shape-retaining capability means the ability of the mat to resist skewing of the edges of the mat relatively, and resistance to undesirable deformation that would decrease its reinforcing properties.

Preferably, the longitudinally-extending fibers as well as the transverse and oblique fibers of the mat are glass fibers. However, the entangling fibers extending from the batting desirably have a bending resistance less than that of the glass fibers. To this end, the batting is preferably of a cut-staple, synthetic resin material such as a polyester. These fibers therefore can also be used to form the conventionally used veil to keep the glass away from a finished surface of the pultruded product. The longitudinal and transverse layers are also preferably interconnected by polyester stitches which are applied to the mat layers utilizing conventional stitching equipment that is generally available and has long been used in the textile industry.

A preferred mat in accordance with this invention has series of holes formed in the mat layers which extend through the thickness of the mat layers and receive binding resin therein that upon hardening, adds to the overall strength of the mat.

In accordance with the preferred method of preparing a mat for use as reinforcement of a resin composition to be used in forming an elongated pultruded part, a composite mat body is prepared which includes a layer of glass fiber rovings extending longitudinally of the mat body in the 0° direction and a thicker layer of transverse glass fiber rovings laying against the longitudinal fibers at a 90° angle with respect to the longitudinal fibers. Two mat layers are also incorporated in the mat body having oblique fibers which extend at an angle of about ±45° with respect to the longitudinal length of the elongated fibers. Thus, the fibers of the oblique fiber layers are positioned such that fibers of one layer are located at an oblique angle of about +45° with respect to the longitudinal length of elongated fibers. The fibers of the other oblique fiber layer are located at an -45° angle with respect to the longitudinal length of the elongated fibers in a direction opposite the angularity of the fibers of the first oblique fiber layer referred to above. Use of oblique fibers, one-half of which extend diagonally from one side of the mat to the other, while the other half extend diagonally to the other side of the mat, provide shear strength stiffness and anti-skewing resistance along both sides of the mat.

Desirably, a relatively thin polyester batting layer is brought into association with the longitudinally extending fibers, those at 90° with respect to the longitudinally extending fibers, and the oblique fibers. Hydro-entangling equipment, or a series of relatively closely-packed,

barbed penetration needles are employed, to deflect at least certain of the fibers of the batting layer into and through the other layers to interconnect the fibers of the various layers and increase the integrity of the layers of the mat in its final completed form.

Provision of the reinforcement fibers which extend transversely of the mat at substantially a 90° angle with respect to the pull direction of the mat enhances the reinforcing effect of such fibers in that there is little or no wasted forces in other directions.

The improved reinforcing mat for pultruded product has high strength to weight characteristics, is flexible for utilization in pultruded parts of complex and varied shape, is economical to manufacture, and can be used in standard pultrusion processes without significant modification of those procedures. Furthermore, the mat can be fabricated as a unitary body of indefinite length which can be readily cut width-wise thereof to any desired width to fit a particular pultruded part.

Brief Description Of The Drawings

The invention will now be described in conjunction with the accompanying drawings in which:

Figure 1 is a schematic, cross-sectional view through a typical finished pultruded fenestration part;

Fig. 1A is an enlarged, fragmentary detail of a portion of the fenestration component shown in Fig. 1 as outlined by the circular bullet;

Fig. 2 is a further enlarged, fragmentary, essentially schematic detail of a part of the fenestration component as shown in Figs. 1 and 1A;

Fig. 3 is a schematic flow diagram of a pultrusion process and the equipment employed for carrying out the present invention;

Fig. 4 is a schematic, greatly enlarged, fragmentary bottom view of a preferred embodiment of a mat prepared in accordance with this invention and useful for reinforcing the resin composition utilized to pultrude a product of the type illustrated in Fig. 1;

Fig. 5 is a fragmentary, cross-sectional view taken substantially along the line 5-5 of Fig. 4;

Fig. 6 is a schematic, greatly enlarged, fragmentary plan view of an alternative embodiment of a reinforcement mat in accordance with this invention;

Fig. 7 is a fragmentary, cross-sectional view taken substantially along the line 7-7 of Fig. 6;

Fig. 8 is a fragmentary, cross-sectional view taken substantially along the line 8-8 of Fig. 6;

Fig. 9 is a schematic representation of apparatus for fabricating a mat in accordance with this invention;

Fig. 10 is an enlarged, schematic depiction of a hydro-entangler identified as a water-jet and forming a part of the apparatus shown in Fig. 9;

Fig. 11 is a fragmentary, greatly enlarged, plan view of an alternative embodiment of a mat prepared in accordance with this invention and useful for reinforcing the resin composition utilized to pultrude a product of the type illustrated in Fig. 1;

Fig. 12 is a fragmentary, cross-sectional view along the line 12-12 of Fig. 11;

Fig. 13 is a fragmentary, cross-sectional view along the line 13-13 of Fig. 11;

Fig. 14 is a fragmentary, greatly enlarged, cross-sectional view of a further embodiment of a reinforcing mat in accordance with this invention;

Fig. 15 is a fragmentary, greatly enlarged, plan view of another embodiment of a reinforcing mat in accordance with this invention;

Fig. 16 is a fragmentary, cross-sectional view taken along the line 16-16 of Fig. 15.

Fig. 17 is an enlarged, fragmentary, schematic representation of needle apparatus as an alternative for forming a series of holes through the thickness of the mat; and

Fig. 18 is an enlarged, fragmentary view of a representative needle useful in the apparatus of Fig. 9.

In the drawings like characters of reference indicate corresponding parts in the different figures.

DETAILED DESCRIPTION

A typical fenestration product which for example may comprise a pultruded part 10 in the form of a window sash rail is shown Fig. 1. It can be seen from this figure that the cross-sectional shape of a part 10 of a fenestration product is of fairly complex configuration which typically has heretofore been difficult to fabricate on a uniform, cost-effective basis because of the inability to reinforce the pultrusion resin with an effective reinforcement material. Part

10 as shown comprises a hollow, closed, pultruded body 12 having uniformly spaced outer wall structure 14 and inner wall structure 16. As schematically shown in Fig. 2, wall structures 14 and 16 each include a reinforcement mat 18 on opposite sides of the central resin body 20 having longitudinally-extending glass reinforcing roving 22 therein. A mat is generally applied on the inside and the outside surfaces of a complex shape, as for example illustrated in Fig. 1. The mat applied to the inside and outside surfaces of the part offers a skin to the pultrusion. The skin serves to give the pultrusion wall transverse strength, by delivering transverse oriented glass rovings to the exterior of the laminate. Longitudinally extending rovings function to give the pultruded part longitudinal strength and modulus.

In most cases, it is necessary to provide symmetry of the mat layers to allow the assembly of fibers to pass through the die. One simple example of the shape is shown in Fig. 1 but it will be appreciated that the shape will vary in accordance with requirements and the shape shown is merely intended to be representative of shapes suitable for various end uses. Simple shapes such as rods in most cases do not need the transverse strength of the mat, whereas more complex shapes such as those used for fenestration profiles always use mat on the inside and outside. A relatively thin layer 24 of the resin making up body 20 covers the outer face of each of the reinforcement mats 18.

In Figs. 4 and 5, a preferred embodiment 18a of the mat 18 is schematically illustrated in plan view and cross-section, respectively. Mat 18a includes a series of separate, transversely-spaced, elongated rovings 28 defining a first layer 30 made up of a large number of relatively fine glass fibers extending longitudinally in the pull direction of mat 18a in what may be characterized as the 0°direction. These rovings should be in the range of 0° to about +20° and 0° to about -20° with respect to the longitudinal length of the mat, with it being understood that there should be a substantially equal number of rovings extending in opposite directions to provide for a balanced pull of a mat through a pultrusion die.

A second set of spaced glass fiber rovings 32 defining a transverse reinforcement second layer 34 extend at an angle of about 90° transversely of mat 18a with respect to the longitudinal axes of rovings 28 making up the first layer 30. The fibers are formed by rovings which extend continuously across the width of the mat 18a and are also preferably glass fibers. Thus, the fibers of the reinforcement second layer 34 are substantially wholly laid directly across the width of mat 18a and are defined by rovings laid side-by-side. The 90° orientation

of the fibers in transverse rovings 28 maximizes the transverse strength and increased modulus of the pultruded part 10, thus reducing the amount of fibers that must be provided transversely of the mat 18a. Rovings 32 are desirably positioned in substantially directly side-by-side, slightly spaced relationship to form a blanket of fibers without substantial breaks therebetween. In lieu of the preferred 90° orientation of rovings 32, the rovings may be positioned at other angularities within the range of about 60° up to 90° in the plane of the mat.

Desirably, the individual rovings 32 are substantially larger in cross-sectional size than the cross-sectional dimension of each of the elongated rovings 28, as is evident from the schematic representations of Figs. 4 and 5. The transverse reinforcement fibers making up rovings 32 constitute an amount in the range of about 50% to about 90% of the total fiber content in the mat 18a.

An angular transport roving layer 36 for assisting in the transfer of the reinforcement layer 34 is located adjacent layer 34 and comprises a plurality of spaced glass fiber rovings 38 located at an angle of about 45° with respect to rovings 28 of reinforcing layer 30. Again, the rovings 38 are of substantially less cross-sectional thickness as compared with the cross-sectional thickness of transverse glass rovings 32.

Another angular transport roving layer 40 is located on the side of transport layer 36 away from transverse layer 34. The glass fiber rovings 42 are desirably at angle of 45° with respect to rovings 38, and therefore in this instance are oriented oppositely of the orientation of rovings 38. Thus, the angularity of rovings 38 may be characterized as + 45° while the angularity of rovings 42 may be characterized as - 45° with respect to the longitudinal axes of rovings 28 of layer 30.

The rovings 38 of layer 36 and rovings 40 of layer 42, extending in opposite directions at 45° angles with respect to rovings 32 of layer 34 extend symmetrically across the width of mat 18a between opposed edges 43 and 45 imparting preferred shear strength to the mat 18a. This increased shear strength is attributable to the fact that rovings 38 of layer 36 and rovings 42 of layer 40 transmit forces substantially equally in the opposite directions to the edge portions 43 and 45 of the mat. By providing such diagonally and oppositely oriented fibers at + 45° and - 45°, there is little tendency for one of the edge portions 43 or 45 to move in advance of the other edge and thus generate a twisting or skewing action which could not be accommodated during pultrusion of part 10. Thus, the angular roving layers 34 and 36 present

a third layer of diagonal transport fibers for the transverse reinforcement fibers of layer 34 to provide shear strength stiffness and anti-skewing resistance to the mat. Again, the oblique or diagonal rovings 38 and 42 are continuous and straight across the width of the mat so as to maximize transmission of forces in respective diagonal directions. Alternatively, the oblique rovings 38 and 42 of angular layers 36 and 40 may be positioned in diagonal directions within the range of about +30° to about +60° and from about -30° to about -60° respectively. Here again, the amount of diagonal fibers extending in one or a plus direction should substantially equal the quantity of diagonal fibers extending in the opposite or minus direction, so that there is an anti-skewing and shear strength stiffness modulus jointly provided by the diagonally oriented fibers.

Layer 30, in conjunction with layers 36 and 40, gives the mat 18a dimensional stability in the 0° and 45° directions so that the mat 18a can be preformed to shape, yet offer sufficient tracking consistency and necking-resistance for consistent processing during pultrusion. An entanglement batting layer 44 (Fig. 5), and preferably comprising thermoplastic fibers such as polyester fibers, is shown as being located against the outer face of angular roving layer 40, although the batting layer 44 may if desired be placed against the outer face of the first layer 30 having longitudinally-extending glass rovings. The batting layer 44 has a series of relatively short fibers 46 randomly oriented in the batting and at least certain of which are intertwined or entangled throughout all three dimensions of the batting, as explained in detail hereinafter. A proportion of fibers 46a (not illustrated in Fig. 5) are deflected from the plane of batting 44 and extend as entanglement fibers through the layers 30, 34, 36 and 40, respectively, entangling and interconnecting glass fibers of glass rovings 28 of layer 36, rovings 32 of layer 34, rovings 38 of layer 36, and rovings 42 of layer 40.

The entangling fibers 46a which carry substantially through the thickness of mat 18a function to integrate the layered structure of the mat and prevent the layers from separating or moving relatively one with respect to another as the reinforcement mat is pulled through the pultrusion die, thus providing required temporary longitudinal, transverse and diagonal strength and twisting resistance during the pultrusion process.

All of the glass fiber layers (34°-90°, 30°-0°, and 36°, 40°, +45° and - 45°) are preferably combined into a web by stitching with polyester thread 47 using a conventional multi-head stitching machine used in the textile industry. It can be seen in Figs. 4 and 5 that

the polyester stitches 47 pass through and interconnect all of the glass layers 30, 34, 36 and 40 of mat 18a. It is to be appreciated that the thread representations in Figs. 4 and 5 are schematic only, and that the heads of the stitchers are in relatively closely spaced relationship, causing the individual stretches of thread to also be in proximal relationship. By virtue of the flexibility of the individual stitches interconnecting layers 30, 34, 36 and 40, the mat component made up of the stitched glass layers also remains highly flexible, although interconnected in a stabilized manner by the polyester threads. Natural fiber thread, as for example cotton, may if desired, be used in place of the preferred polyester thread. In lieu of the provision of stitches 47, which are preferred, the layers 30, 34, 36 and 40, may be consolidated in a monolithic body by provision of a material such as a thermoplastic resin binder. The binding action of the binder can be supplemented, with a thermoplastic resin sheathing on certain or all of the glass fibers of the rovings 28, 32, 38 and 42, or such resin sheathing may if desired take the place of an added thermoplastic binder.

The batting layer 44 is hydro-entangled with the 0° roving layers, transverse roving layers, and angular roving layers of the mat 18a. Entanglement is preferably accomplished by subjecting the laminar structure made up of a batting layer, two angular roving transport layers, the transverse roving reinforcement layer, and the 0° pull direction layer of the pre-mat, to the action of water-jets from multiple banks of water nozzles. The individual water jets force certain of the polyester fibers 46 into locations extending throughout the mat 18a as shown in Fig. 5.

The individual jets of water wet the randomly-oriented fibers of the polyester batting web 44 directly to the glass web layers 30, 34, 36 and 40 and force certain of the polyester fibers 46 into locations 46a extending throughout the mat 18a. As shown for example in Fig. 5, the hydro-entangled fibers 46a act as between-glass bundle spanners, and within-glass bundle spanners, resulting in a somewhat flexible, and continuous mat product. It is also to be understood that the water jets from the hydro-entangler unit also break up some of the fibers of the layers 30, 34, 36 and 40 to produce shorten tangling glass fibers randomly oriented in the same manner as entangling fibers 46a and extending throughout the cross-sectional extent of layers 30, 34, 36 and 40. These broken glass entangling fibers cooperate with polyester fiber entangling fragments 46a to maintain the layers 30, 34, 36 and 40 in proper relative

relationship during processing of mat 18a and in the use thereof as a reinforcement for a pultruded part.

The mat product 18a is preferably calendered to reduce loft, needled to increase permeability, and padded with a PVA or similar binder material, to increase the dry-mat stiffness. The calendering, needling, and padding steps can be rearranged, processed multiple times, or omitted if the glass layers are thermally bonded with a resin as explained in detail hereinafter, depending on the desired permeability, stiffness, and thickness required for the mat, to optimize the pultrusion process, and the mechanical properties of the pultruded fenestration product, such as a window frame sill.

The fiberglass for the 90° glass fibers of roving 32 is preferably a 900 yield E-glass roving that has been treated with an organo-silane sizing composition to increase reinforcement-matrix interfacial strength. The +/- 45° oriented glass fibers 38 and 42 and the 0° direction glass fibers 28 are preferably G150's (15000 yards per pound) with a thermoplastic resin sheathing as recommended and supplied by Engineered Yarns Incorporated of Fall River, MA. The polyester material making up batting web 44 preferably consists of a blend a 60% Wellman 1.5 denier x 1.5" polyester staple fiber, and a 40% Kosa 1.5 denier by 1.5" long bicomponent fiber, crimped and baled. The Kosa fiber gives the batting web 44 a heat-fusible component, while the Wellman fiber enhances the consistency of the polyester batting and decreases shrink of the web during heat-fusing. After the blend is mixed, an opener filamentizes the fibers.

The fibers are then air laid as a batting web 44 via the Rando process onto the fiber glass substrate made up of layers 30, 34, 36 and 40. The batting web is hydro-entangled to the fiber glass substrate, dried, calendered to consolidate and reduce loft, needled to improve permeability, and then chemically treated via a padding operation where a PVAc coating is applied to the mat to improve handling properties.

The preferred material of batting 44 is a polymer such as randomly-oriented, cut-staple polyester fibers in which there are ends of the fibers extending across the width of the mat. The reduced thickness and the cut ends of the polyester mat allow the hydro-entangling jets to grasp the fibers and to carry parts of the fibers across from the plane of the mat into and through the fibrous glass layers to the underlying plate, thus effecting entangling of certain of the fibers of the batting mat with the underlying glass roving layers. The polyester fibers of the batting mat

may be grasped by the water-jets at the end of a fiber or at an intermediate location of the fiber. The fibers making up batting 44 should be of characteristics such that the fibers have a relatively low resistance to bending so that fibers may be moved downwardly through hydro-entanglement, or by mechanical structure such as barbed needles or the like. Glass fibers of reduced denier meeting the requisite flexibility requirements may be also used as a batting material for the hydro-entangling layer 44 of mat 18a.

The speed of the reinforcement mat 18a during manufacture of that mat is desirably about 15-25 ft. per minute. A preferred mat width is 20 in., but a wider mat can be fabricated using larger equipment. To create the mat 18a, glass roving supplied as a packaged spool is placed on a creel, and fed onto a set of parallel belts. The glass fibers of roving 32 are wound around needles along each edge of the endless belt, to arrange the glass fibers for the desired orientations. The fibers of longitudinal roving 32 and the fibers making up the roving of angular layers 36 and 40 preferably have been pre-coated with a thermoplastic synthetic resin comprising an amide, a polyester, or a similar sheath-like binder. When subjected to elevated temperature, the sheathing binder flows and thereby fuses the glass fibers of all of the glass layers of the mat 18a together, thereby producing a windable glass pre-mat. Preferred results have been obtained by using 11 courses per inch of roving 36, making up 90° reinforcement layer 34, about 8 courses per inch of 45° angular, diagonal fibers, and about 8 courses per inch of 0° fibers in an assembled pre-mat for mat 18a.

Meanwhile, the non-woven batting web 44 is made by blending of polyester staple fibers. The staple fibers are blended and opened in a Sigma Fiber Controls non-woven opener. The polyester fibers are then fed through a Rando webber so that a density of approximately 32 gram/square meter is reached. The Rando feed and doff speeds are set at about 2.5 and 1.0 respectively. The polyester non-woven web 44 is then combined with the glass pre-mat as described above.

The glass pre-mat with non-woven polyester web applied is fed into a hydro-entangler 66, as for example shown schematically in Fig. 10, on a fine-mesh belt to supplement jet reflections, to help to entangle the mat 18a. A suitable hydro-entangler is commercially available from ICBT Perfojet of Mont Bonnet, France. In general, the hydro-entangler 66 has upper manifold structure 68 receiving water from supply source 70 provided with a plurality of openings or nozzles 72 which direct water jets 74 directly onto mat 18a. The water-jets

delivered from nozzles 72 are preferably pulsed so that the jet streams exit through respective nozzles 72 and pass through the thickness of mat 18a until impacting the upper surface of a fine mesh belt 76. The water streams impacting against the upper surface of belt 76 cause the water to dissipate and thereby spread the fibers carried by the jet streams transversely across the top of the plate 76 to enhance entanglement of mat 18a.

The ICBT Perfojet hydro-entangler has three horizontally-spaced manifolds of the type shown schematically in Fig. 10, each having a row of water-jet nozzles 68, with the nozzles spaced at approximately eight per inch, providing a total of 100 to 150 nozzle openings. The water is jetted onto the mat 18a with the first manifold set at a water pressure of 500 psig, the second at 500 psig, and the third at 1200 psig. The mat 18a becomes entangled with fibers 48 as the water jets from manifold 66 pass through the layered material making up mat 18a. The mat 18a in web form is directed under a vacuum duct, drawing most of the water from the mat.

The hydro-entangler has the capability to blow-in holes or enhance existing holes in the mat, to achieve higher permeability. Permeability is useful to allow resin to flow through the thickness of the mat in the pultrusion die, to avoid harmful hydraulics or bubbling of the mat at the pultrusion die entrance. The hole size and distribution are enhanced by the needling operation or the hydro-entangling process. When enhanced by the hydro-entangling, the hole size and distribution are determined by the hydro-entangler back screen pattern and back screen mesh size. A mesh size of 40 x 40 wires/inch in the backside conveyor belt that transports the mat through the hydro-entangling process has been used to create a hole pattern in the mat of 40x40, to increase the permeability. A mesh of 10 x 10 is favored, however, because this coarse mesh allows for larger holes, corresponding to a higher and more desirable permeability. A permeability of 200-400 cubic feet per minute of air, through the mat (at a pressure differential of 0.5" of water) is sufficient for pultrusion, but a permeability of 600-800 or higher works very well for subsequent pultrusion processing.

The mat 18a then passes through a 15-foot diameter drum drying oven, such as one available from National Drying of Cary, NC, and that uses 200°F air forced through the thickness of the mat 18a to dry all of the layers thereof.

In lieu of using a hydro-entangler as described, a head (not illustrated) may be provided which supports a series of barbed needles 142 as shown in Fig. 18. In this case, the batting mat layer 44 should be opposite the points 142a of the needles so that when the barbed needle

penetrate the mat, the barbs 142b do not engage the fibers 46 of batting mat layer 44. However, upon retraction of the barbed needles 142, the barbs 142b thereon engage certain of the relatively short fibers 46 and pull all or at least a portion of such fibers upwardly into the glass roving layers to entangle the glass fibers with the polyester batting fibers 46.

The mat 18a is then calendered through smooth 12 in. diameter rolls on a B.F. Perkins calender set at 120°C with a minimum gap of 0.007 in., to reduce the mat thickness, and fuse the polyester material into the glass pre-mat. The calendered mat 18a is rolled, and allowed to cool to ambient temperature.

The entangled mat 18a is then unrolled and fed into a Dilo needler with a needle board using #16 needles spaced six-rows deep. The Dilo needler uses barbless needles to achieve a 10 x 10 holes-per-inch density. The punch depth is 14 mm, take off gear is set at 7, the base gear at 1.75, resulting in a stroke rate of 300 per minute, at a 1 meter/minute advance rate. During needling, the needles are heated to 160° F, by use of electric heat guns placed inside the Dilo needle box area, and blowing air through the length of the needle board.

The mat is next fed into an A. G. Mathis padder to apply a 2:5 solution of Franklin Duracet 600 PVAc, diluted with tap water. The mat picks up this binder, and is then squeezed through the rubber drying rolls set at 30 psi, at the given speed per the needling process. The mat passes through another identical National Drying of Cary, NC,15-foot diameter drum drying oven that uses 200°F air forced through the thickness to dry the mat.

The mat is then slit longitudinally to the desired width for pultrusion, and fed into the pultrusion machine with resin-saturated glass rovings.

Equipment for pultruding a part 10 using a mat 18 as an outer skin reinforcement on one or both sides of the part is illustrated schematically in Fig. 3. Pulling mechanism 52, which for example may comprise roller structure, is operable to pull part 10 from a pultrusion die 54 of the transverse configuration of the part to be produced.

As depicted schematically in Fig. 3, a mat 18' prepared in accordance with this invention as previously described may be directed from a source roll 116 over schematically illustrated roller 118 and 120, thence through resin bath 122, over roller 124 and into the pultrusion die 54. A web 126 of glass roving from source roll 128 passes over roller 130, through resin bath 132, and then over rollers 134, 136 and 138 into the die 54. Mat 18a is supplied from source roll 140 and across rollers 118 and 120 into bath 122 and across roller 124

into die 54. A conventional pultrusion resin formulation may be used for pultruding part 10 with a typical formula which, for example, may include a mixture of thermoset polyester resin containing a reactive diluent such as styrene, along with a hardener, a catalyst, a calcium compound filler, a suitable surface modifier, and a die lubricant.

It is understood that the representation in Fig. 3 is schematic only and intended to indicate that mats 18' and 18" the longitudinally-extending rovings 126 are located such that mat 18' is one skin layer of the pultruded part, glass rovings 126 are centrally disposed of the part, and mat 18" is positioned as an opposite skin layer of the part. Furthermore, instead of passing the roving and the batting mat through respective resin baths, as shown schematically in Fig. 3, resin may be applied to the roving and the batting using conventional resin-applying procedures that are well known to those skilled in this art.

An adhesive binding material such as PVA in a water carrier and containing about 20% to about 60% solids, corn starch or other adhesive material well known to one skilled in the art can be used to assist in interconnecting the structure so that the entangled fibers are bonded to the fibers of the layers 30, 34, 36 and 40 and the fibers are bonded to each other. Generally, the binding agent is present in an amount in the range of 2% to 20% by weight (dry weight without water). However, the amount of binding agent is significantly reduced relative to conventional non-woven mats and thus the stiffness of the structure is very much reduced and therefore improved, allowing the reinforcement mat to bend to take up the complex shape of the part to be formed while restricting shear.

If thermoplastic fibers are used for entangling, the binder can be reduced or even omitted and instead the fibers heated to provide some amount of heat bonding to each other and to the glass or main fibers. In the arrangement shown in Fig. 9, some of the entangling fibers are of a high melting point so that they remain intact and thus act as entangling fibers, and some are of a lower melting point so that they act as bonding fibers.

The mat 18 as described provides reinforcement which has sufficient structural strength in the longitudinal and shear directions to ensure that it will be transported through the pultrusion die without significant longitudinal deformation. This is attributable to the fact that the main bulk of the fibers are arranged in the transverse direction to provide the finished product with the required transverse strength. The number of fibers therefore necessary for a

predetermined transverse strength is significantly reduced since the bulk of the fibers are arranged in the direction to maximize the strength provided by each fiber.

Referring specifically to Fig. 9, apparatus 78 includes a conveyor belt 80 arranged to carry the components of the mat 18 from an initial supply to a wind-up device 82. The components of the mat 18 are laid onto the belt in required sequence from a supply thereof which includes a plurality of supply units generally indicated by the numeral 84.

Diagonal roving supply head 86 functions to lay down glass fiber rovings 42 at an angle with respect to the longitudinal length of belt 60 and preferably at an angle of about 45°. The head 86 traverses back and forth across belt 60 in timed relationship to the speed of the belt 60 to provide diagonally-oriented glass rovings. Glass fiber rovings supply head 88 is operable to reciprocate back and forth across the width of belt 60 to lay down transverse glass fiber rovings 32, again in timed relationship to movement of belt 60, to provide rovings which are at a 90° angle with respect to the path of travel of belt 60. Supply head 90 continuously lays down glass rovings 28 along the longitudinal length of belt 60, thus providing a 0° lay of rovings.

Diagonal roving supply head 92 lays down a glass fiber rovings 38 on the previously-applied rovings, at a 45° angle opposite the angularity of rovings 42. Thus, the rovings 38 may be characterized as + 45° and the rovings 42 characterized as - 45° with respect to the longitudinal length of the rovings laid down on belt 60 and thereby with respect to rovings 28.

The mat structure so formed is passed through a set of hot rolls 98 which act to elevate the temperature of the materials previously laid down on belt 60 so that when glass rovings are used that have a polymer sheath thereon as described above, the polymers decrease sufficiently in viscosity at the operating temperature of the apparatus 78 to flow through and assist in bonding of the layers of the mat one to another upon solidification in the final product. The rolls 98 act also to calender the mat so that it is compressed and slightly reduced in thickness. In some cases the heat may be omitted and simple calendering action be used.

When the glass fiber pre-mat so formed is consolidated by the bonding action, an air lay machine 100 receives cut-staple fibers of a suitable polymer such as polyester from a source thereof which may include a proportion of high melt fibers that withstand a temperature of about 350°F, and a remainder of low melt fibers which melt at about 270°F. These fibers are blended and laid by the air lay machine onto the top surface of the mat previously formed. The

details, construction and operation of equipment for air laying of staple fibers is well known to those skilled in the applicable art.

After the staple fibers are laid onto the mat, the collated structure is passed through the water-jet hydro-entangler 66 shown in Fig. 10 and described above. The belt 60 terminates after the entangler and the collated and combined mat is laid onto a drum dryer 102 which extracts the water previously applied in the water-jet entangler as the mat structure passes around the periphery of the drum dryer.

Downstream of the dryer 102, the mat again passes between a pair of hot rolls 106 which act to further calender the mat and also to melt and activate the polyester fibers to provide a bonding action. A needler or perforator 108 has a head 110 which supports a plurality of parallel, relatively closely-spaced needles 112 (Fig. 17) located downstream of the hot rolls 106. The head 110 is reciprocated to sequentially direct the needles 115 through the mat to form an array of perforations. The array includes perforations spaced both longitudinal and transversely so the series of needles across the width of the mat are punched through the mat as the mat moves forwardly to provide the required number of spaced perforations thus increasing the porous nature of the mat to allow penetration of resin to bond through the mat into the various components of the mat. From 1 to 5000 holes per square inch may be formed in the mat using perforator 108, but about 80 holes per square inch formed by #14 needle size is preferred in a rectangular grid pattern. The needler 108 may be of conventional design which functions at a rate of approximately 20 cycles or reciprocations per second. The holes may be round or polygonal and generally are of a diameter what may be characterized as pin holes. The hole pattern may be random, square, rectangular, close-packed-hexagonal, or similar configurations.

A PVA binder, or an equivalent powdered, solvent, thermal or aqueous based thermoplastic binder is applied to the mat 18 by dispenser 113.

Following perforation of the mat and application of the binder, it is slit by slitter 114 into a plurality of tapes or bands of the required width for use in the subsequent pultrusion process. Each band is then packaged in a suitable manner for example by winding onto a roll so the roll can be transferred to the supply section of the pultrusion process as described hereinbefore.

The mat formation may also be carried out on-line with the pultrusion process so as to avoid the winding and supply steps although in general this is unlikely to be practical in many circumstances due to the different speeds of the processing lines.

The reinforcement mat 18a is made in multiple process steps, beginning with deposit of glass rovings 34, and angular layers 36 and 40 on a conventional needle support, which are thereafter laid on the longitudinal rovings 28 of layer 30, or, in the alternative, the longitudinal rovings may be laid down first followed sequentially by layers 34, 36 and 40. The layers 34, 36, and 40 may then be interconnected by stitching as with polyester threads 47. The batting layer 44 is then placed against the outermost face of the outer transport layer 40 forming a part of the stitched mat layers.

Rovings 32 of reinforcement layer 34 and made up of glass fiber bundles are festooned in the transverse direction (90° with respect to the pull direction of the part 10), generally 2-32 courses per inch to form a web (broadgood). Smaller reinforcement bundles of transport glass fibers 38 and 42 are laid in the + 45° and - 45° directions are placed sequentially on top of the transverse layers 34, as shown schematically in Fig. 5. These three layers are then positioned over the rovings 28 making up the 0°layer 30.

The batting 44 is preferably a relatively thin web of polyester staple fibers laid down by a conventional air machine. These polyester staple fibers are blended and carded, and a predetermined thickness is achieved by stacking of a plurality of staple-fiber webs. The polyester batting in the form of a web is laid on top of the angular layer 40, or in the alternative, over the 0° rovings 28, or as a further alternative, over both of the layers 36 and 40.

In the alternate embodiment of the invention as shown in Figs. 6, 7 and 8, the mat 18b has a 0° layer 30' made up of a series of longitudinally extending glass rovings 28' which is illustrated as being in direct overlying relationship to transverse layer 34' made up of a series of side-by-side glass rovings 32'. Angular fiber layers 36' and 40' made up of rovings 38' and 42', respectively, are located on opposite faces of the 0° roving layer 30' and transverse roving layer 34', respectively, as best shown in Figs. 6 and 7. A batting layers 44' of the same material as previously described, is illustrated as being positioned in overlying relationship to the outer face of angular roving layer 36'. Batting layer 44' is comprised of a series of relatively short fibers, such as polyester fibers 46', with the hydro-entangled fibers being designated by the numeral 46a.

The transverse speed at which supply heads 86 and 92 lay down the diagonally-oriented glass rovings 42 and 38 may be adjusted with respect to the velocity of belt 60 to vary the angularity of the transport glass rovings across the width of the mat on belt 60 from the preferred angularity of about +/- 45° to angles within the range of about +/- 30° to about +/- 60°.

In an alternate embodiment of this invention, the diagonal glass rovings 38 and 42 may be replaced with additional quantities of the transverse glass rovings 32 making up reinforcement layer 34 so that the resultant strength of the fibers in the finished pultruded part lies primarily or generally in the transverse direction.

In another alternate embodiment of the pre-mat before the addition of the batting layer as depicted in Figs. 11-13, two longitudinally-extending glass fiber roving layers 144 and 146 are provided on opposite sides of centrally-located, substantially larger glass fiber rovings in transverse layer 148. Two oppositely-diagonal glass fiber roving layers 150 and 152 are positioned against the face of longitudinal layer 144 opposite transverse layer 148. The glass fiber roving layers 150 and 152 are preferably oriented in opposite diagonal directions at about 45° with respect to the longitudinal length of the mat.

Figure 14 illustrates another embodiment similar to the Fig. 13 embodiment except in this instance, a batting mat layer 154 is positioned on top of the diagonal glass fiber roving layer 150. In this figure, relatively short fibers of the batting mat layer are schematically shown as being entangled with the glass fiber layers 144-152, inclusive.

When diagonal glass rovings 38 and 42 are laid down at 70° angles with respect to the longitudinal length of the mat, as shown in Figs. 15 and 16, in many instances the longitudinal rovings 28 may be omitted in that the diagonal rovings provide adequate dimensional stability in the direction of pull to prevent canting, or distortion of the reinforcing mat 18b while passing through pultrusion die 52.

<u>EXAMPLE 1-Thermally Bonded</u>

The mat, in a resin matrix, provides the high transverse strength on the surface of the exterior or interior of a pultruded part such as a sash stile or rail, or a pultruded frame head, sill, or jamb, or other products outside the fenestration industry. The cross-section of the pultrusion profile consists of a matrix of thermosetting resin with longitudinal- and/or other-rovings in the

middle of the profile thickness, and the mat on the outside surfaces (interior surface in the case of a hollow profile). The mat portion of the laminate is about 0.010" thick, the longitudinal-roving area is about 0.030" thick, and the opposite mat is also about 0.010" thick. The longitudinal-roving-fibers are oriented in the 0° direction. These longitudinal-fibers are mostly 675-yield (yards per pound) fiberglass rovings.

A construction of a reinforcement mat, with the longitudinal direction (e.g. the continuous direction) designated as the 0°-0° direction in the plane of the mat, comprised of:

a first layer of a plurality of 1800-yield fiberglass fibers rovings, substantially in the transverse, or 90° direction in the plane of the mat set at 10 courses per inch;

a second layer of a plurality of an amide, polyester or reactive sheathed fiber glass bundles spaced 4 per inch, in the +/- 45° direction in the plane of the mat, thermally bonded to the transverse fiberglass;

a third layer of a plurality of an amide, polyester or reactive sheathed fiber glass bundles spaced 4 per inch, in the 0° direction in the plane of the mat, thermally bonded to the transverse fiberglass;

a fourth layer of a plurality of polyester fibers that have at least portions thereof which extend in the thickness direction through the third, second and/or first layer to effect a connection there-between, with a pre-entangled weight of 32 grams per square meter;

with holes primarily between the transverse 1800-yield roving, like sieve-holes in the through-thickness direction, with the holes numbering eighty per square-inch in a rectangular grid pattern;

with a PVA-based binder to adhere the multiple layers and/or the interstices within a given layer;

with the entire mat thickness (slightly compressed during thickness measurement) at approximately 0.010-inches;

and a back-side with alternately-spaced 0° fibers as a third layer of a plurality of an amide, polyester or reactive sheathed fiber glass bundles spaced 4 per inch, in the 0° direction in the plane of the mat, thermally bonded to the transverse fiberglass.

<u>EXAMPLE 2--Polyester Stitched</u>

The mat, in a resin matrix, provides the high transverse strength on the surface of the exterior or interior of a pultruded sash stile or rail, or a pultruded frame head, sill, or jamb. The cross-section of the pultrusion profile consists of a matrix of thermosetting resin with longitudinal- and/or other-rovings in the middle of the profile thickness, and the mat on the outside surfaces (interior surface in the case of a hollow profile). The mat portion of the laminate is about 0.010" thick, the longitudinal-roving area is about 0.030" thick, and the opposite mat is also about 0.010" thick. The longitudinal-roving-fibers are oriented in the 0° direction. These longitudinal-fibers are mostly 675-yield (yards per pound) fiberglass rovings.

A construction of a reinforcement mat, with the longitudinal direction (e.g. the continuous direction) designated as the 0° direction in the plane of the mat, comprised of:

a first layer of a plurality of 1800-yield fiberglass fibers rovings, substantially in the transverse, or 90° direction in the plane of the mat set at 10 courses per inch;

a second layer of a plurality of 6-denier polyester thread spaced 6 per inch, in the +45° direction in the plane of the mat, stitched to the transverse fiberglass;

a third layer of a plurality of a 6-denier polyester thread spaced 6 per inch, in the 0° direction in the plane of the mat, stitched to the transverse fiberglass;

a fourth layer of a plurality of 6-denier fibers that have at least portions thereof which extend in the thickness direction through the third, second and/or first layer to effect a connection there-between, with a pre-entangled weight of 32 grams per square meter;

with holes primarily between the transverse 1800-yield roving, like sieve-holes in the through-thickness direction, with the holes numbering eighty per square-inch in a rectangular grid pattern;

with a PVA-based binder to adhere the multiple layers and/or the interstices within a given layer;

with the entire mat thickness (slightly compressed during thickness measurement) at approximately 0.010-inches;

and a back-side with alternately-spaced 0° fibers as a third layer of a plurality of a 6-denier polyester thread spaced 6 per inch, in the 0° direction in the plane of the mat, and stitched to the transverse fiberglass.

EXAMPLE 3--Fiberglass Stitched

The mat, in a resin matrix, provides the high transverse strength on the surface of the exterior or interior of a pultruded sash stile or rail, or a pultruded frame head, sill, or jamb. The cross-section of the pultrusion profile consists of a matrix of thermosetting resin with longitudinal- and/or other-rovings in the middle of the profile thickness, and the mat on the outside surfaces (interior surface in the case of a hollow profile). The mat portion of the laminate is about 0.010" thick, the longitudinal-roving area is about 0.030" thick, and the opposite mat is also about 0.010" thick. The longitudinal-roving-fibers are oriented in the 0° direction. These longitudinal-fibers are mostly 675-yield (yards per pound) fiberglass rovings.

A construction of a reinforcement mat, with the longitudinal direction (e.g. the continuous direction) designated as the 0° direction in the plane of the mat, comprised of:

a first layer of a plurality of 1800-yield fiberglass fibers rovings, substantially in the transverse, or 90° direction in the plane of the mat set at 10 courses per inch;

a second layer of a plurality of fiberglass fiber bundles spaced 4 per inch, in the +45° direction in the plane of the mat, stitched to the transverse fiberglass;

a third layer of a plurality of a 6-denier polyester thread spaced 4 per inch, in the 0° direction in the plane of the mat, stitched to the transverse fiberglass;

a fourth layer of a plurality of polyester fibers that have at least portions thereof which extend in the thickness direction through the third, second and/or first layer to effect a connection there-between, with a pre-entangled weight of 32 grams per square meter;

with holes primarily between the transverse 1800-yield roving, like sieve-holes in the through-thickness direction, with the holes numbering eighty per square-inch in a rectangular grid pattern;

with a PVA-based binder to adhere the multiple layers and/or the interstices within a given layer;

with the entire mat thickness (slightly compressed during thickness measurement) at approximately 0.010-inches;

and a back-side with alternately-spaced 0° fibers as a third layer of a plurality of a fiberglass bundles spaced 4 per inch, in the 0° direction in the plane of the mat, and stitched to the transverse fiberglass.

Since various modifications can be made in our invention as herein above described, and many apparently widely different embodiments of same made within the spirit and scope of the claims without departing from such spirit and scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.